

LANSCCE DIVISION TECHNOLOGY REVIEW

DANCE—A Detector for Advanced Neutron Capture Experiments

J.L. Ullmann, R.C. Haight, L.F. Hunt, E.H. Seabury (LANSCCE Division), R.S. Rundberg, M. Dragowsky, M.M. Fowler, G.G. Miller, L. Pangault, J.B. Wilhelmy (C Division)

A new instrument for nuclear physics research is being built on FP14 at the Lujan Center. This state-of-the-art instrument consists of a shell of 160 barium fluoride crystals, each 15 cm long, with an inner radius of 17 cm. DANCE will be used to study the neutron-induced transmutation of radioactive elements. This process is of interest in understanding the synthesis of the chemical elements in stars, in studying the burn-up of nuclear waste, and in gaining a better understanding of archived data from past tests of nuclear explosives. Los Alamos is unique in the world in being able to make these measurements.

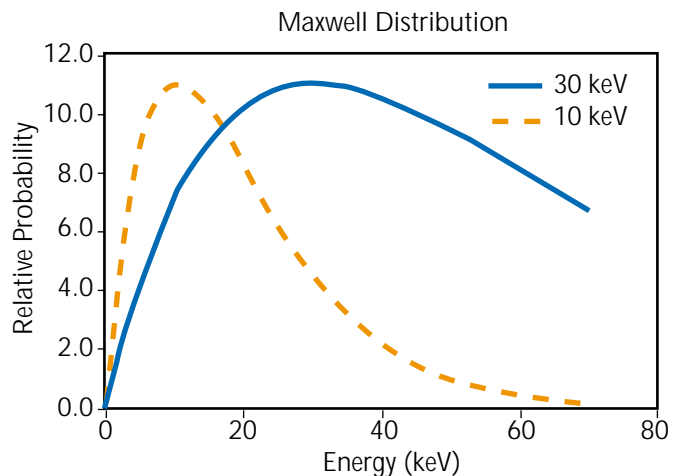
Why Study Neutron Capture Today?

Neutron capture is a reaction in which a neutron strikes and sticks to a target nucleus, forming a new isotope. An example of this type of transmutation reaction is the absorption of a neutron by the element ^{171}Tm to form ^{172}Tm . Usually, this new isotope is not in its ground state (the lowest energy state of a nucleus), but it rapidly decays to its ground state by emitting a cascade of gamma rays. The total energy emitted, Q , is given as $Q = M(A+1) - M(A) - M(n) + E_{\text{neut}}$, where $M(A)$ is the mass of the nucleus with atomic number A , $M(n)$ is the mass of the neutron, and E_{neut} is the center-of-mass energy of the neutron. The emitted gamma ray rarely has the total energy, and multiple gamma rays are usually emitted, corresponding to transitions between different nuclear levels. Typically, five or six gamma rays are emitted, each with an energy ranging from about 0.1 to 5 MeV.

The probability for neutron capture has been measured on most stable nuclei over a wide range of neutron energies. Theoretical calculations of the reaction probabilities, or cross sections, can only reproduce these measurements to within a factor of two because the process is very sensitive to details of the nuclear structure. The cross section varies with neutron energy, and for certain energies and elements, the ratio between measurement and calculation can be much greater. Currently, cross sections are needed on unstable nuclides for several problems, including understanding the synthesis of heavy elements in

stars, the archived data from nuclear explosion tests, and the process behind transmuting or burning waste. Because calculations do not provide sufficient accuracy, measurements of neutron capture on these radioactive nuclei are needed, and exceedingly few measurements have been made.

The neutron energies of interest are typically from a keV to near an MeV. [Energies in nuclear reactions are measured in kilo-electron volts (keV). Stars like our Sun have energies around 1 keV.] Stellar nucleosynthesis by the slow, or s-process, which is thought to produce half of the elements heavier than iron, is believed to take place at stellar temperatures around 10 to 30 keV. The neutron energy distributions corresponding to these temperatures are shown in Fig. 1. The water moderators at the Lujan Center provide an excellent source of neutrons in this energy range.



▲ Fig. 1. The Maxwell energy distribution for neutrons at stellar temperatures of 10 and 30 keV.

DANCE Will Use Unique Capabilities at Los Alamos

The advanced detector for neutron-capture measurements that we are building is only one of the facilities required for these important neutron-capture experiments. The intense, pulsed neutron source of the

Lujan Center is required to make measurements on small quantities of target material. In fact, preliminary measurements using less efficient detectors have been made on 1-mg samples of ^{171}Tm with a 1.92-yr half-life. Even less material will be required to make measurements on shorter half-life or less-benign radioactive targets. The radioactive material handling and fabrication facilities of C Division at Los Alamos, including the new Radioactive Species Isotope Separator, will be used to safely fabricate targets. The location of the three components necessary to make capture measurements on radioactive targets—target fabrication facilities, an intense neutron source, and an advanced detector—is unique in the world at Los Alamos.

Measuring Neutron Capture

The DANCE detector was designed to have high efficiency for gamma-ray detection, to have good neutron-energy resolution by time of flight, and to be relatively insensitive to experimental backgrounds. Extensive Monte Carlo calculations were done to aid in the design process.¹

High efficiency is needed to minimize the amount of radioactive material used for a target. For example, 1 mg of the 1.92-yr half-life nuclide ^{171}Tm produces 1.1-Ci rate of nuclear decay, and 1 Ci corresponds to 3.7×10^{10} decays per second. The need for high efficiency rules out the use of high-purity germanium detectors, which would provide excellent gamma-ray energy resolution but at a very high cost. The alternative we chose was to use scintillating crystals coupled to photomultiplier tubes.

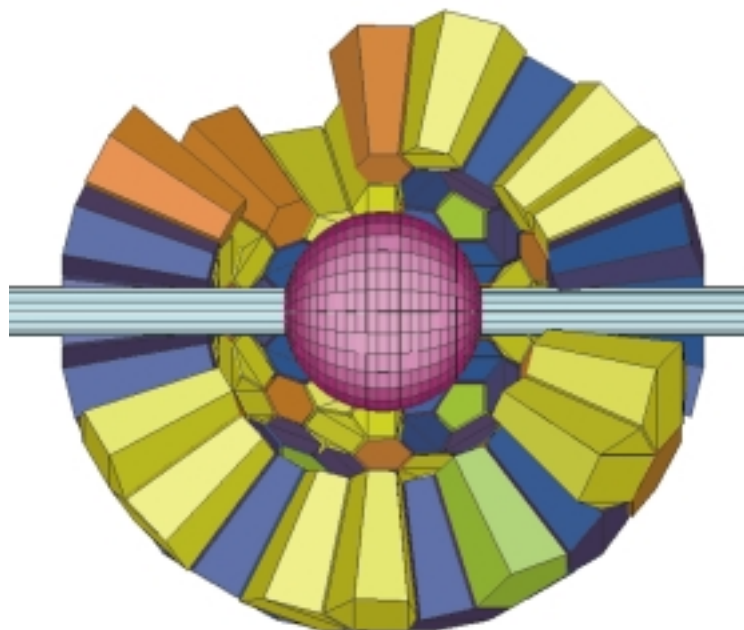
Background gamma rays can come both from the decay of the target and from neutron capture in detector and beam-line components induced by scattered neutrons. Target decays can produce a high background rate. A 1-Ci target, such as ^{171}Tm , produces 370 decays in 10 ns. Thin shielding and high detector thresholds could be used to reduce the backgrounds associated with low-energy gamma rays from these decays. However, to measure higher-energy gamma rays, we need a highly segmented detector made of a material with a very fast response time, such as barium fluoride.

Neutrons can be scattered into the detector from the target backing material, beam halos, and the target itself

because the scattering probability often exceeds the capture probability. These scattered neutrons can be captured in the detector material, producing background gamma rays. The background from scattering can be reduced by using neutron absorbers, such as ^6LiH or B_4C , in front of the detector and by making the detector from materials with low-neutron-capture cross sections. Barium, for example, has one of the lowest-neutron-capture cross sections of the elements used in scintillating crystals.

With these considerations in mind, we are using a 160-segment BaF_2 crystal array designed as a calorimeter to capture all the gamma rays emitted by the target. Because the total energy, Q , is constant, a measurement of the total energy of the gamma-ray cascade provides a means of discriminating a true capture signal from the background. The segmented array also allows another way of identifying true capture events by means of cluster analysis. Gamma rays from a true capture in the target produce several clusters of hits in the array, whereas a capture in the array itself results in a single, large cluster of hits.

One way to completely cover a spherical surface is with 162 segments with four different geometric shapes. This is similar to a soccer ball, where twelve pentagons and twenty hexagonal segments are required. Two segments are left blank, for the beam to enter and exit the array. This geometry is shown schematically in Fig. 2. Fig. 3 shows the support structure for the crystal array, Fig. 4 shows a prototype of one of the four shapes of BaF_2 crystals, and



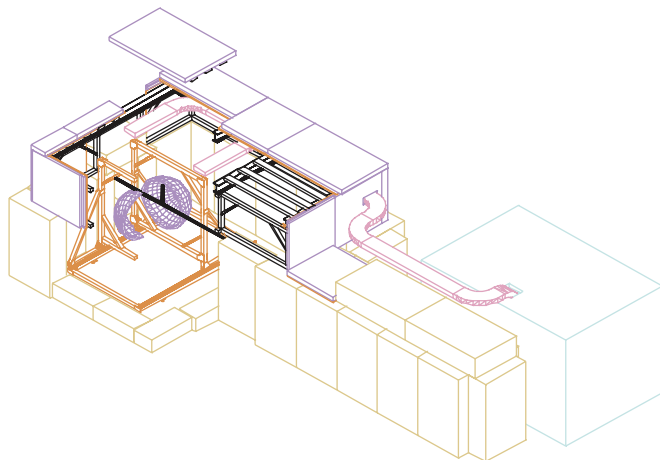
▲ Fig. 2. Schematic representation of DANCE.



▲ Fig. 3. John Ullmann of LANSCE-3 examines the DANCE support structure.



▲ Fig. 4. Prototype of one of the four crystal shapes. The crystal is 15 cm long.



▲ Fig. 5. DANCE experimental area.

Fig. 5 is a schematic representation of the DANCE experimental area. The complete BaF_2 array will have an inner radius of 17 cm, and each crystal is 15 cm long. There is space for a 6-cm-thick shield and neutron absorber between the inner surface of the BaF_2 and the beam pipe.

Construction on FP14

The DANCE detector is being installed on FP14 at the Lujan Center. The neutron FP consists of four discrete collimators each consisting of alternating copper and 5% borated polyethylene layers with changeable inserts. Each collimator section is 81 cm long and consists of a total of 51 cm of copper and 30 cm of borated polyethylene. The last collimator ends at 19.2 m from the moderator, and the target location is designed to be at 20.5 m. The last collimator is 0.6 cm in diameter, which results in a beam spot that is uniform out to $r = 0.3$ cm at the target location and falls to 1/100 of the central flux by $r = 0.75$ cm.

The BaF_2 array is designed to be separated into two sections and can be opened to install the various targets. The radioactive targets will be sealed in evacuated 2-in.-diam beam pipes at C Division's radioactive-isotope-handling facilities so that no handling of radioactive material will be required at the Lujan Center. Various configurations of gamma shielding and neutron absorbers will be used around the target pipe as required by the individual target characteristics. The neutron beam flux will be monitored using the ${}^6\text{Li}(n,\alpha)$ reaction by a beam monitor downstream of the detector.

The construction of the FP is nearly complete. The mechanical support for the advanced detector has

been constructed, and barium fluoride crystals are arriving from the manufacturer. The completion date depends on the production capability of the crystal manufacturer. We anticipate completion of the full array in the summer of 2002. At that time, a program of measuring several targets a year will be started. In the meantime, measurements on less demanding targets will be made with a partial array.

Reference

1. M. Heil, R. Reifarth, M. M. Fowler, R. C. Haight, F. Kaeppler, R. S. Rundberg, E. H. Seabury, J. L. Ullmann, J. B. Wilhelmy, and K. Wisshak, "A 4π BaF_2 Detector for (n,γ) Cross Section Measurements at a Spallation Neutron Source," to be published in *Nuclear Instruments and Methods in Physics Research*; M. Heil *et al.*, "GEANT Simulations of Neutron Capture Experiments with a 4π BaF_2 Detector," Los Alamos National Laboratory report LA-UR-99-4046.

For more information, contact J.L. Ullmann (LANSCE-3), 505-667-2517, MS H855, ullmann@lanl.gov

Produced by the LANSCE communications team:
Barbara Maes, Sue Harper, Garth Tietjen,
Sharon Mikkelsen, and Grace Hollen.



A U.S. DEPARTMENT OF ENERGY LABORATORY
 Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36



<http://lansce.lanl.gov>